OAK RIDGE NATIONAL LABORATORY
operated by
UNION CARBIDE CORPORATION
NUCLEAR DIVISION
for the
U.S. ATOMIC ENERGY COMMISSION

ORNL-TM-1911

REMOVAL OF ELEMENTAL IODINE FROM STEAM-AIR ATMOSPHERES BY REACTIVE SPRAYS

L. F. Parsly, Jr.

DISCLAIMER

ORNL-TM-1911

Contract No. W-7405-eng-26

CFSTI PRICES

REACTOR DIVISION

H.C. $ 3.00; MN .65

REMOVAL OF ELEMENTAL IODINE FROM STEAM-AIR ATMOSPHERES BY REACTIVE SPRAYS

L. F. Parsly, Jr.

OCTOBER 1967

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee
Operated by
UNION CARBIDE CORPORATION
for the
U.S. ATOMIC ENERGY COMMISSION

pe9

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

CONTENTS

REMOVAL OF ELEMENTAL IODINE FROM STEAM-AIR ATMOSPHERES BY REACTIVE SPRAYS

L. F. Parsly, Jr.

ABSTRACT

This report describes a computer program for calculating mass transfer rates for removal of I_2 from steam-air atmospheres by reactive sprays. It includes procedures for calculating the transport properties revealed in the mass transfer rate calculations. The calculations predict half-lives for I_2 removal of 30 seconds or less, indicating that an effective spray system can prevent the leakage of I_2 from a containment building. The removal half-lives are not greatly affected by temperature up to 150°C.

Experiments are planned to verify the calculated results. These are based on I_2, and while we would expect HI to be removed at least as fast, we believe removal of organic iodides and particulate matter would probably be slower.

INTRODUCTION

In many power reactors now under design, sprays are being installed for the purpose of removing heat from the reactor containment building in the unlikely event of a loss-of-coolant accident. Since it would be advantageous to use the sprays to remove released fission products as well, consideration is being given to adding reagents to the sprays to effect removal. Therefore, tests of removal of fission products by sprays are being planned.

We believe the overall spray problem includes at least the following sub-problems:

Removal of I_2 and/or HI by sprays (gas-film controlled absorption)

Removal of organic iodides by sprays (mechanism not clear at this time, either liquid film or reaction kinetics controlled)

Removal of particles by sprays.

The present report addresses itself only to the first of these. Absorption technology is quite well developed, although there is less published information concerning spray chambers than concerning other systems. Therefore, we felt that it ought to be possible to make some reasonably good predictions of spray performance from existing data. We needed estimates of removal rates in order to decide how we should attempt to measure them.

The work reported here comprises the writing of a computer program to calculate gas-phase mass-transfer coefficients over a considerable range of temperature and drop size. It includes complete documentation of the equations used in the calculation so that the reader can evaluate the work. In order to do the calculations, we had to calculate properties such as diffusion coefficients of iodine in air-steam mixtures, viscosities of air-steam mixtures, and terminal velocities of water drops in air-steam mixtures. The procedures used for these calculations and the results obtained are reported.

In all of our calculations, we have used a "constant volume" model. That is: we assume that we start with a fixed volume of air at 30°C and 1 atmosphere and introduce enough open steam to produce saturated air at the temperature we want to study. This should duplicate the atmosphere in a containment building after a loss-of-coolant accident. The effect of using this model is that pressure and density increase markedly with temperature.

SUMMARY AND CONCLUSIONS

Calculations have been made which show that I_2 should be removed from a containment building atmosphere very rapidly by reactive sprays. The predicted half-lives are of the order of seconds. While these calculations involve a number of simplifying assumptions, it seems reasonable to expect the calculations to predict the I_2 removal rate at least within an order of magnitude. Removal of I_2 at even one-tenth of the calculated rate would effectively eliminate it as a hazard to people off-site. HI should be removed at least as rapidly as I_2 by the reactive sprays; but organic iodides and iodine associated with particles probably would not. As soon as experimental confirmation of the I_2 removal rates is obtained, we should start to deal with the problem of handling organic iodides and particles.

The calculations show that we must be prepared to measure a very rapid transient. Therefore measurements with instruments, rather than sampling, must be relied on to determine rates.

The removal of a reactive constituent from the containment atmosphere follows the exponential decay law:

$$C_G/C_{Go} = \mathrm{EXP}\ (-V_g A t)$$

In order to set up a problem which could be calculated easily, we made the following assumptions: all of the drops are the same size; they are falling at their terminal velocities; the absorption process is gas-film controlled. The true situation is that there is a spectrum of drop diameters; the liquid enters through the spray nozzle orifice at a velocity higher than terminal and the drops actually slow down. The assumption of gas-film controlled absorption appears to be correct, however. Using the above assumptions, one calculates a value of V_GA which applies throughout the volume and is independent of time and vessel height.

The calculations indicate that we can expect half-lives in the general range of 1.5 sec (100 μ drops, 1 gpm flow to the vessel, room temperature) to 33 sec (1000 μ drops, 15 gpm flow, 120^{o}C). Therefore measurements with instruments capable of rapid response to changes, rather than sampling, must be relied on to measure rates.

ABSORPTION THEORY*

The generally-accepted theory for momentum, heat and mass transfer from a continuous phase to a boundary system postulates a turbulent core which is assumed to be completely mixed and a laminar boundary layer in which shear, temperature, and concentration gradients exist.[1,2] Transfer coefficients are defined as follows:

$$k_c = \frac{N_A}{C_G - C_{Gi}} \tag{1}$$

$$k_L = \frac{N_A}{C_{Li} - C_L} \tag{2}$$

$$K_c = V_G = \frac{N_A}{C_G - C_{L/H}} \tag{3}$$

From the above it follows that:

$$\frac{1}{V_G} = \frac{1}{k_c} + \frac{1}{Hk_L} \tag{4}$$

---

*The symbols used in the theoretical development in this reaction are defined in the Nomenclature section at the end of the report.

If $k_c \ll Hk_L$, V_G becomes essentially equal to k_c and the system is said to be gas-film controlled. This is true for absorption of iodine into reactive solutions.

The heat-mass-momentum transfer analogy leads to the following relationships:[2]

$$N_{Nu} = \phi\ (N_{Re},\ N_{Pr}) \qquad (5)$$

$$N_{Sh} = \phi\ (N_{Re},\ N_{Sc}) \qquad (6)$$

with the function being the same for (5) and (6).

Although there has been only limited work on absorption by sprays, much has been done on heat transfer. Ranz and Marshall[3] have proposed the following relationship:

$$N_{Nu} = 2.0 + 0.6\ N_{Re}{}^{1/2}\ N_{Pr}{}^{1/3} \qquad (7)$$

based on spray-drying experiments. Sideman[4] has recently published a comprehensive review article which applies to the problem. For heat transfer from a continuous phase to rigid drops he reports 16 proposed equations of which 8 are in the general form of (7) and he presents a graph of these which strongly supports the position that equation (7) is a reasonable choice. We therefore have chosen the following equation for our calculations:

$$N_{Sh} = 2.0 + 0.6\ N_{Re}{}^{1/2}\ N_{Sc}{}^{1/3} \qquad (8)$$

COMPUTER PROGRAM

A program has been written in Fortran 63 for the CDC 1604 computer to carry out the necessary calculations. It does the following things:

> Given a temperature, it calculates the partial pressure of air and water vapor, the total pressure, and the density and viscosity of the mixture. It then calculates the diffusivity of iodine in air, water and in the mixture.
>
> For each of several drop diameters, it calculates the terminal velocity of the drop in the air-stream mixture and the deposition velocity of iodine onto the drop.

A listing of the computer program is given in Appendix "A" of this memorandum. The program comprises a main program titled "SPRAY," a subroutine VSUBT for calculating the terminal velocities and a subroutine DSUBV for calculating the diffusion coefficients.

In this section of the report we document our calculation by presenting all of the equations we have used and the sources from which they were obtained.

Main Program "SPRAY"

The main program does the following calculations:

a. Calculates the vapor pressure of water from the following equation from Keenan and Keyes.[5]

$$\log_{10} \frac{218.167}{P} = \frac{x}{T} \left[\frac{a'+b'x + c'x^3}{1+d'x} \right] \tag{9}$$

$x = 647.27-T$

$a' = 3.2437814$

$b' = 5.86826\text{x}10^{-3}$

$c' = 1.1702379\text{x}10^{-8}$

$d' = 2.1878462\text{x}10^{-3}$

b. Calculates the specific volume of liquid water. For this purpose, we fitted the following equation to tabulated data in the Handbook of Chemistry and Physics[6] for the temperature range 20° to 150°C (the equation in Keenan and Keyes[5] contains a graphic term and therefore was not suitable):

$$V = 1.0018 + 0.0062615(t-20) + 3.219 \times 10^{-6}(t-20)^2 \tag{10}$$

This equation represents the tabulated data within 0.05% over the temperature range.

c. Calculates the specific volume of steam from the following equation given by Keenan and Keyes:[5]

$$V = \frac{4.5504T}{p} + B \tag{11}$$

$$B = B_o + B_o^2\, G_1(\tau)(\tau p) + B_o^4\, G_2(\tau)(rp)^3 + B_o^{13}\, G_3(\tau)(\tau p)^{13} \tag{12}$$

$$B_o = 1.89 - 2641.62\tau 10^{(80870\tau^2)} \tag{13}$$

$$G_1(T) = 82.546T - 1.6246x10^5T^2 \quad (14)$$

$$G_2(T) = 0.21828 - 1.2697x10^5T^2 \quad (15)$$

$$G_3(T) = 3.635x10^{-4} - 6.768x10^{64}T^{24} \quad (16)$$

d. Calculates the viscosity of steam from the following equation given in Keenan and Keyes.[5]

$$\eta = \eta_o + f_1(p) \quad (17)$$

$$\eta_o = \frac{1.851x10^{-5}(T)^{\frac{1}{2}}}{1 + 680.1T} \quad (18)$$

$$f_1(p) = [0.03103 - 3.65x10^{-5}p]\ px10^{-4} \quad (19)$$

e. Calculates the viscosity of air from the following equation given in the Chemical Engineer's Handbook.[7]

$$\eta = 1.709x10^{-4}\left[\frac{T}{273.16}\right]^{0.768}.$$

f. Calculates the viscosity of the air-steam mixture from the following relationship proposed by Buddenberg and Wilke.[8]

$$\eta_M = \frac{\eta_1}{1 + \frac{x_2}{x_1}\phi_{12}} + \frac{\eta_2}{1 + \frac{x_1}{x_2}\phi_{21}} \quad (20)$$

$$\phi_{12} = \frac{\left[1 + \left(\frac{\eta_1}{\eta_2}\right)^{\frac{1}{2}}\left(\frac{M_2}{M_1}\right)^{\frac{1}{4}}\right]^2}{\frac{4}{\sqrt{2}}\left[1 + \frac{M_1}{M_2}\right]^{\frac{1}{2}}} \quad (21)$$

$$\phi_{21} = \frac{\left[1 + \left(\frac{\eta_2}{\eta_1}\right) \left(\frac{M_1}{M_2}\right)^{\frac{1}{4}}\right]^2}{\frac{4}{\sqrt{2}} \left[1 + \frac{M_2}{M_1}\right]^{\frac{1}{2}}} \tag{22}$$

g. Calculates N_{Sc} for iodine in the mixture.

h. Calculates N_{Re} for each drop size at each temperature.

i. Calculates the gas-film coefficient from the Ranz-Marshall equation (8)

j. Calculates a factor by which the liquid mass flow is to be multiplied to get the drop surface per unit volume.

$$A(L) = \frac{6}{d\ \rho_L\ V_T} \tag{23}$$

$$A = A(L)\ L \tag{24}$$

Subroutine DSUBV

This subroutine calculates the diffusivities of iodine in air and steam using the Wilke and Lee[9] modification of the equation of Hirschfelder, Bird and Spotz.[10]

$$D_v = \frac{BT^{3/2} \sqrt{1/M_1 + 1/M_2}}{p\ r_{12}^2\ I_D} \tag{25}$$

$$B = [10.7 - 2.46 \sqrt{1/M_1 + 1/M_2}] \times 10^{-4} \tag{26}$$

$$r_{12} = \frac{r_{01}\ r_{02}}{2} \tag{27}$$

$$r_o = 1.18\ v_o^{1/3} \tag{28}$$

$$\frac{\epsilon_{12}}{k} = \sqrt{\frac{\epsilon_1}{k} \cdot \frac{\epsilon_2}{k}} \tag{29}$$

For the range of interest in this problem, we fitted the following equation to the tabulated collision integral data.[10]

$$I_D = 0.3674 + 0.3478 \left(\frac{\epsilon_{12}}{kT}\right) \tag{30}$$

The diffusivity of iodine in the steam-air mixture was calculated from the diffusivities in steam and air by the relationship proposed by Wilke.[11]

$$D_{VA'} = \frac{1 - Y_A}{\dfrac{Y_B}{D_{VAB}} + \dfrac{Y_C}{D_{VAC}}} \tag{31}$$

We assumed $Y_A = 0$.

<u>Subroutine VSUBT</u>

This subroutine is used to calculate terminal velocities of the drops in the air-steam mixture. It uses the following equation from Lapple.[12]

$$V_T = 0.153\, g_c^{0.714}\, d^{1.142}\, (\rho_L - \rho)^{0.714} / \rho^{0.286}\, \eta^{0.428} \tag{32}$$

This equation is recommended for use in the transitional range

$2 \leq N_{Re} \leq 1000$

If the Reynolds number exceeds 1000, the terminal velocity is calculated by:

$$V_T = 1.74 \sqrt{g_c\, d\, (\rho_L - \rho)/\rho} \tag{33}$$

RESULTS OF CALCULATIONS

The results of the calculations are presented graphically in Figs. 1-5 inclusive and are tabulated in Appendix B.

Figure 1 presents a plot of the terminal velocity as a function of temperature for 100, 400, 700, and 1000 μ diameter drops. This shows that the terminal velocity decreases approximately 50% as the temperature increases from 20 to 150°C. The decrease in terminal velocity is principally a consequence of the increasing density of the air-steam atmosphere as the temperature increases.

Figure 2 presents a plot of the Reynolds number of the spray drops vs temperature. This plot shows that the Reynolds number goes through a minimum at 40°C and then increases to approximately twice its value at 20° by the time the temperature reaches 150°.

Figure 3 shows the effect of temperature on the diffusivity of iodine in air, steam, and the specific air-steam mixtures in which we are interested. The diffusivities go through a maximum at 40°; this results from the interaction of $T^{3/2}$ in the numerator of the equation and P (which is essentially an exponential function of T) in the denominator.

Figure 4 presents the Schmidt number versus temperature for iodine in the air-steam mixtures of interest. It turns out that the Schmidt numbers are affected to almost a negligible extent by temperature.

Figure 5 shows the deposition velocities, likewise as a function of temperature and drop size. These figures show that the transfer coefficients decrease with increasing temperature and drop diameter.

As an example of how the tabulated data can be applied, suppose we want to find the half-life for I_2 removal from the NSPP, using the presently installed nozzles (Spraco J-140D misting nozzles), which are reported by the manufacturer to give 100 μ drops. Assume a flow of 1 gpm to the MCV.

ORNL-DWG 67-5822

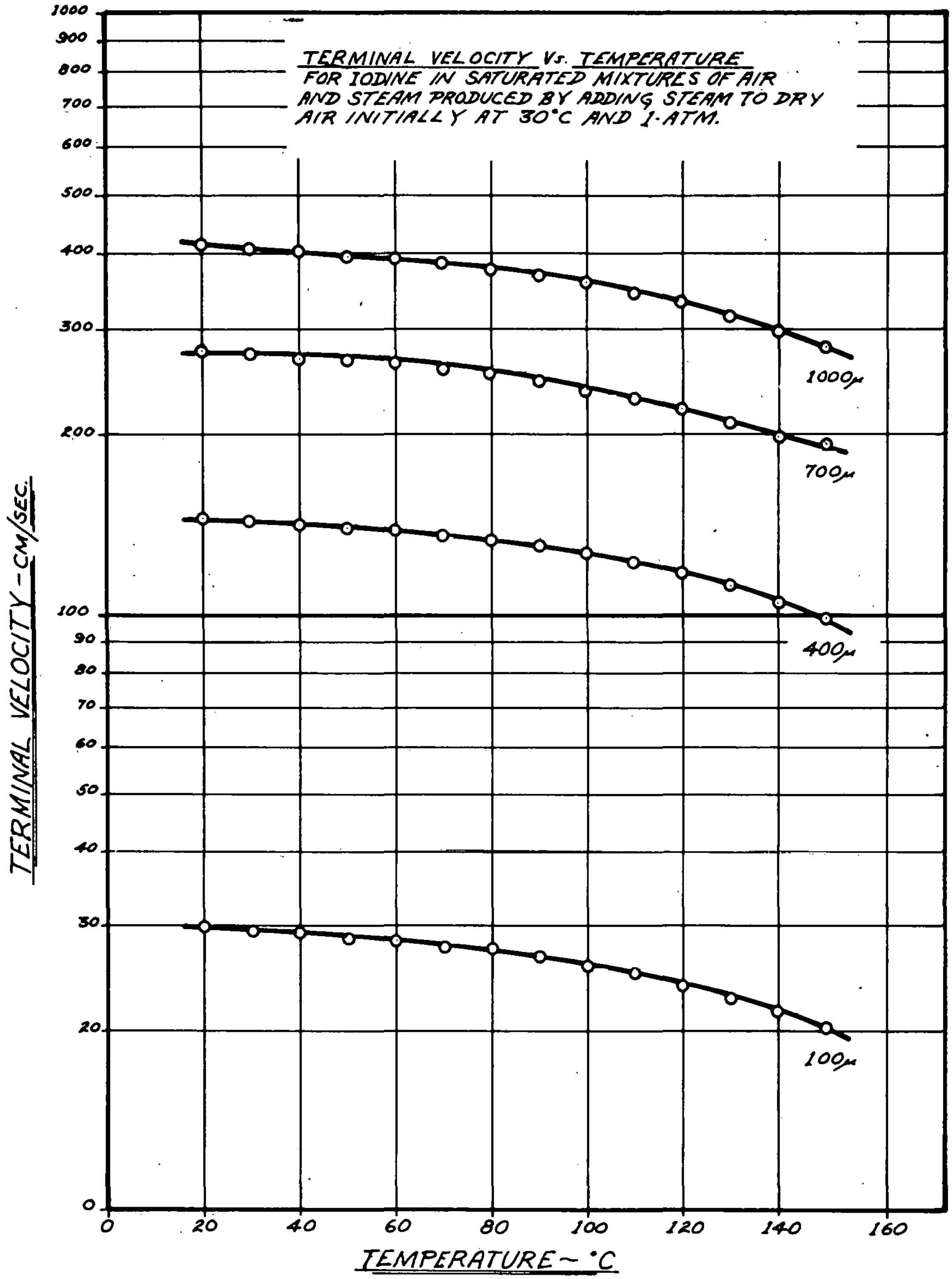

Fig. 1. Terminal Velocity of Drops vs Temperature

ORNL-DWG 67-5823

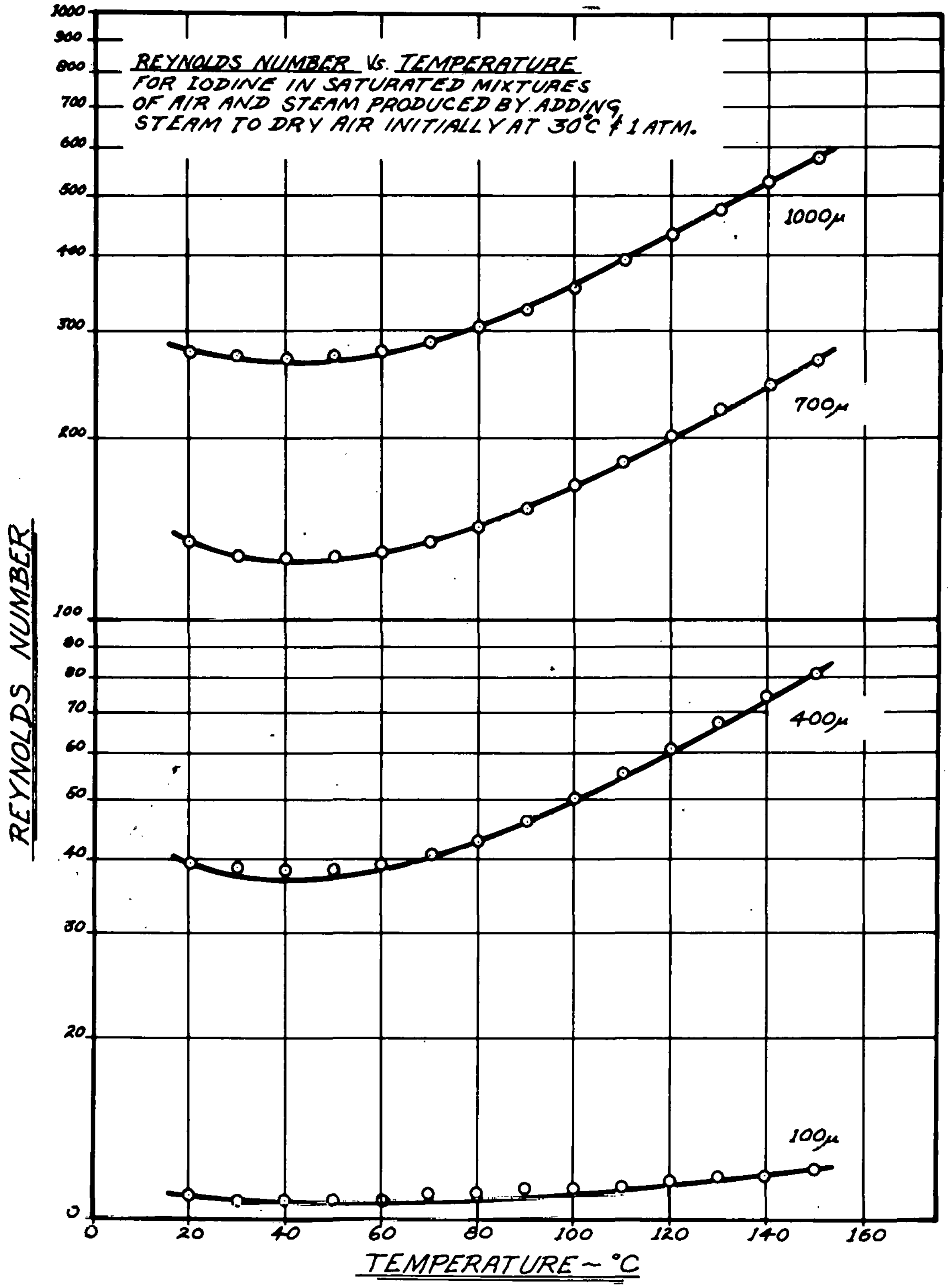

Fig. 2. Reynolds Number of Spray Drops vs Temperature

ORNL-DWG 67-5882

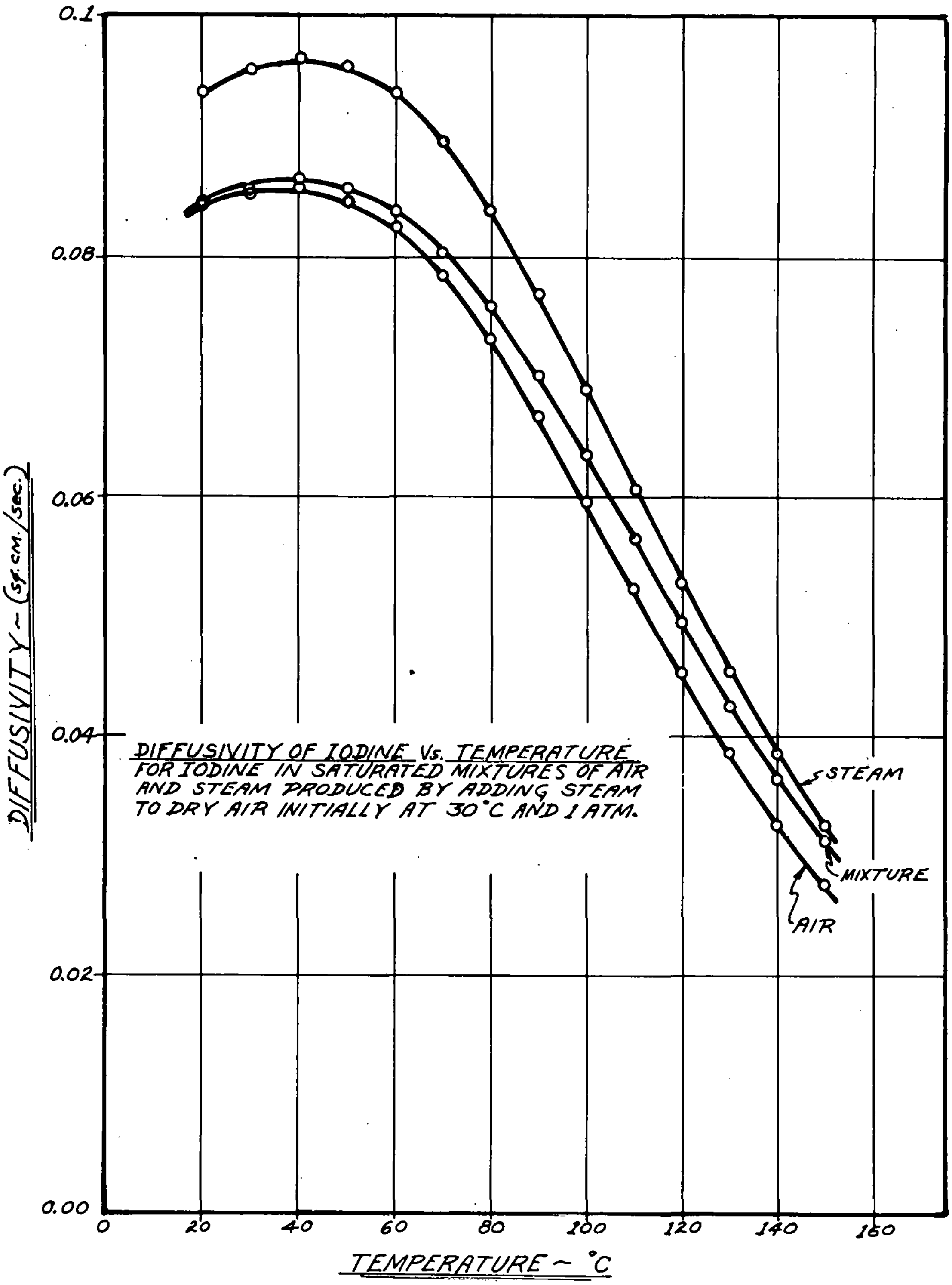

Fig. 3. Diffusivity of Iodine vs Temperature

ORNL-DWG 67-5824

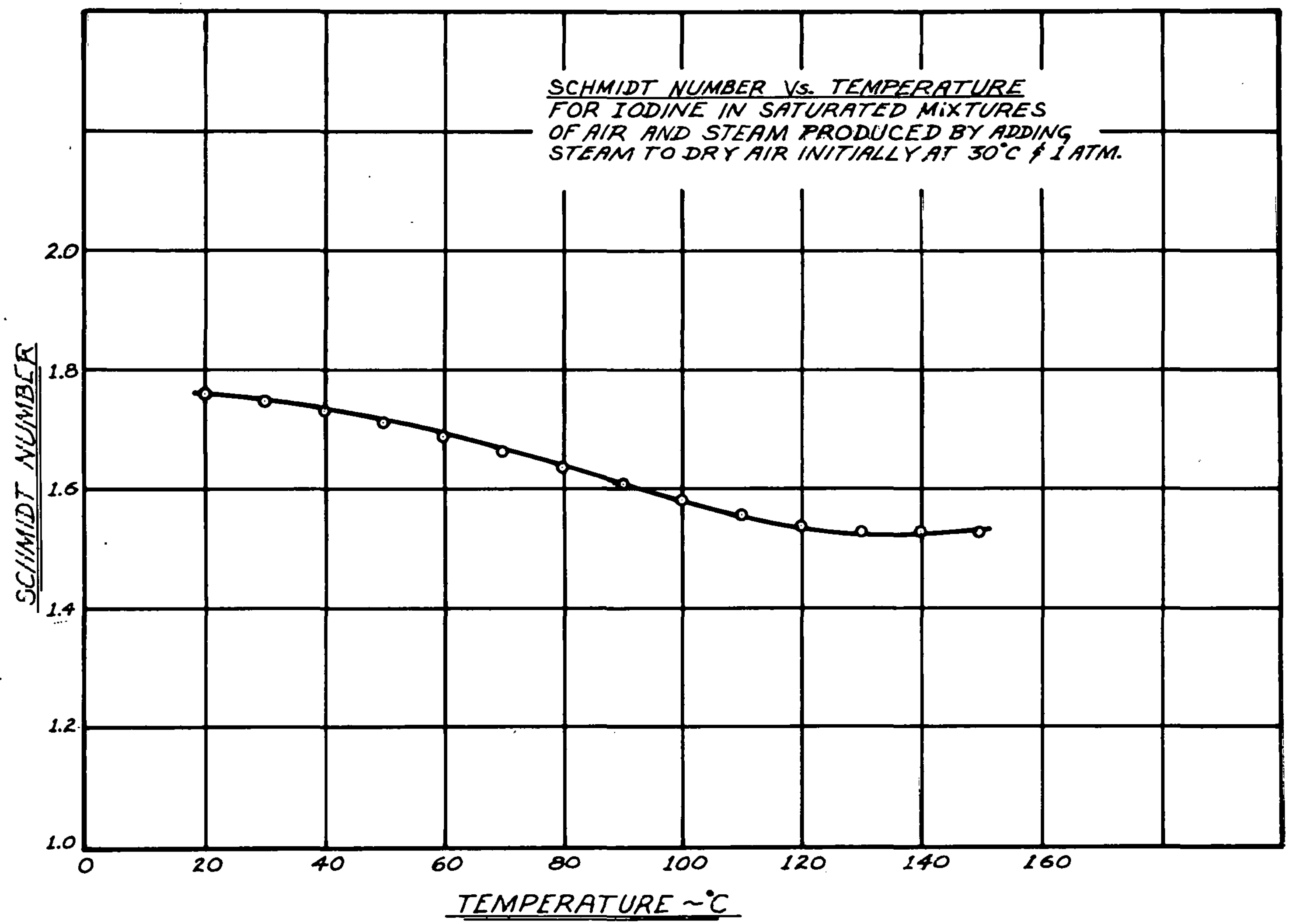

Fig. 4. Schmidt Number vs Temperature

ORNL-DWG 67-5820

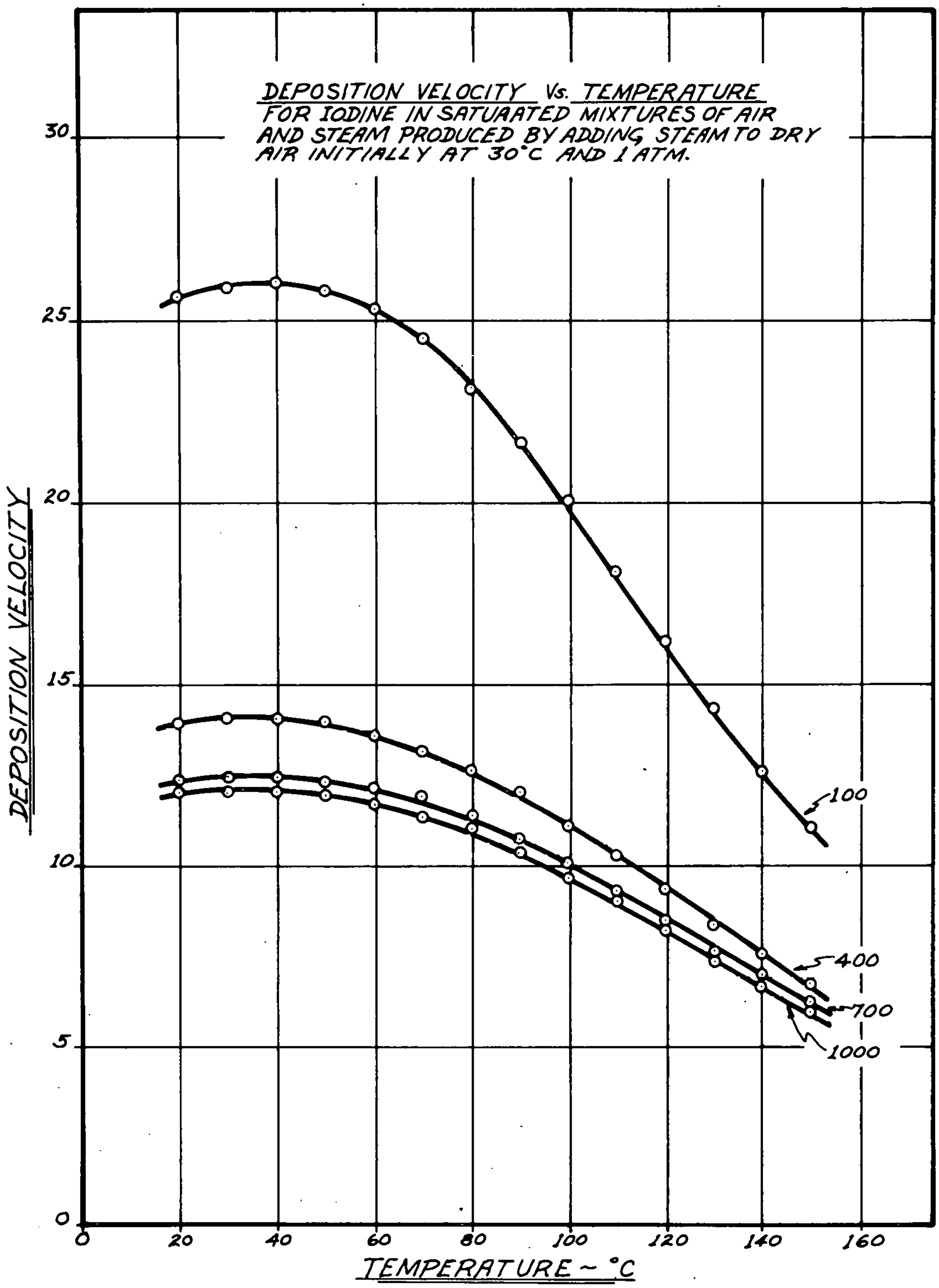

Fig. 5. Gas-Film Deposition Velocity vs Temperature

$$L = \frac{1\ \text{gal/min} \times 3785\ \text{cc/gal}}{60\ \text{sec/min} \times 78.54\ \text{ft}^2 \times 929\ \text{cm}^2/\text{ft}^2} =$$

$$8.64 \times 10^{-4}\ \text{g/cm}^2\ \text{(sec)}.$$

From the table

$$A(L) = 2.01 \times 10^1 \frac{(\text{cm}^2)}{(\text{cm}^3)(\text{g cm}^{-2}\ \text{sec}^{-1})}$$

$$A = 2.01 \times 10^1 \times 8.64 \times 10^{-4} = 1.74 \times 10^{-2}\ \text{cm}^2/\text{cm}^3$$

$$v_G = 2.55 \times 10^1\ \text{cm/sec}$$

$$v_G A = 1.74 \times 10^{-2} \times 2.55 \times 10^1 = 4.437 \times 10^{-1}\ \text{sec}^{-1}$$

$$t_{\frac{1}{2}} = 0.693/v_G A = 1.56\ \text{sec}.$$

DISCUSSION OF RESULTS

These calculations indicate very short half-lives for I_2 removal. While the example given above is perhaps extreme, one calculates for conditions proposed for large power reactor containment buildings (~ 0.01 g/cm^2 (sec) liquid mass flow, 700 μ drop diameter) that the half-lives will be of the order of 15 to 30 sec.

For any practical case, it is necessary to recognize that some simplifications are involved in setting up a problem of this sort and to consider the effect of the simplification on the overall result. The simplifications involved in this calculation are the following:

1) We have assumed that the liquid-film resistance is negligible. We believe this to be reasonably true for the conditions we are interested in. In further development of the program, we think it should be possible to consider the case where both film resistances are significant.

2) We have assumed that the spray pattern was fully developed. In actual experiments there will be a spray start-up transient which may be of significant duration with respect to some of the half-lives.

3) We have assumed that the spray filled the entire volume uniformly. This will never be entirely true, but it always should be more nearly true for an installation using a given nozzle size and type in a large containment building than in the pilot plant.

4) A corrolary assumption is that there are no wall effects. Again, this is more true for the large containment building than for the pilot plant.

5) We have assumed that the drops are all at one uniform velocity - their terminal velocity. Actually, they will enter at a much higher velocity and will slow down to their terminal velocity after the sheet of liquid issuing from the nozzle has broken up into drops.

As a consequence of the above simplifying assumptions, we think it would be fortuitous if the calculated and observed removal half-lives were in agreement and that agreement within a factor of 2 to 3 should be considered highly satisfactory. Since the predicted half-lives are so short, we feel that a half-life of anywhere up to 10 times the calculated value should still permit removal of iodine quickly enough to render insignificant the hazard due to leakage of iodine from the containment building. Thus, if we are able to verify iodine removal half-lives of the order predicted, we believe that we should almost immediately turn our attention to removal of methyl iodide and of particulate matter by the sprays, since these would probably become more critical.

NOMENCLATURE

A	=	Area of drops per unit volume ($cm^2 \cdot cm^{-3}$)
$A(L)$	=	Function defined by Eq. (23)
C_G	=	Concentration in bulk gas ($g\ mols \cdot cm^{-3}$)
C_{Gi}	=	Concentration in gas at gas-liquid interface ($g\ mols \cdot cm^{-3}$)
C_L	=	Concentration in bulk liquid ($g\ mols \cdot cm^{-3}$)
C_{Li}	=	Concentration in liquid at gas-liquid interface ($g\ mols \cdot cm^{-3}$)
d	=	Drop diameter (cm)
D_v	=	Diffusivity ($cm^2 \cdot sec^{-1}$)
g_c	=	Acceleration of gravity ($cm \cdot sec^{-2}$)
H	=	Gas-liquid distribution coefficient ($C_{Li} = HC_{Gi}$)
I_D	=	Collision integral
k_c	=	Gas-film mass-transfer coefficient based on concentration driving force ($cm \cdot sec^{-1}$)
k_L	=	Liquid-film mass-transfer coefficient ($cm \cdot sec^{-1}$)
K_c	=	Overall mass-transfer coefficient based on concentration driving force ($cm \cdot sec^{-1}$)
L	=	Liquid mass flow ($g\ cm^{-2} \cdot sec^{-1}$)
M_i	=	Molecular weight of ith component
N_A	=	Number of mols transferred per unit time per unit area ($g\ mols \cdot cm^{-2} \cdot sec^{-1}$)
N_{Nu}	=	Nusselt number = hd/k
N_{Pr}	=	Prandtl number = $C_p\mu/k$
N_{Re}	=	Reynolds number = $dV\rho/\mu$
N_{Sc}	=	Schmidt number = $\mu/\rho D_v$
N_{Sh}	=	Sherwood number = $k_c d/D_v$
p	=	Pressure (atm)
r	=	Collision radius (Å)
t	=	Temperature (deg. C)
T	=	Temperature (deg. K)
v	=	Specific volume ($cm^3 \cdot g^{-1}$)
V	=	Velocity ($cm \cdot sec^{-1}$)

V_T = Terminal velocity of drops ($cm \cdot sec^{-1}$)

V_G = Deposition velocity for gas (cm/sec)

X_i = Mol fraction of ith component

Y_i = Mol fraction of ith component

η = Viscosity, poises

ρ = Density of gas ($g\ cm^{-3}$)

ρ_L = Density of liquid ($g\ cm^{-3}$)

τ = T^{-1}

REFERENCES

1. R. H. Perry, C. H. Chilton, and S. D. Kirkpatrick, (editors), "Chemical Engineers' Handbook," 4th ed., 1963, Section 14, Gas Absorption and Solvent Extraction.
2. T. K. Sherwood and R. L. Pigford, "Absorption and Extraction," McGraw-Hill Book Co., New York, 1953.
3. W. E. Ranz and W. R. Marshall, Jr., Chem. Eng. Progress 48, 141, 173 (1952).
4. S. Sideman, "Direct Contact Heat Transfer Between Immiscible Liquids" in "Advances in Chemical Engineering," Vol. 6, Academic Press, New York, London, 1966.
5. J. F. Keenan and F. G. Keyes, "Thermodynamic Properties of Steam," John Wiley and Sons, Inc., New York, 1936.
6. C. D. Hodgman (editor), "Handbook of Chemistry and Physics," Chemical Rubber Publishing Co., Cleveland, Ohio, 21st ed., page 1199.
7. J. H. Perry (editor), "Chemical Engineers' Handbook," McGraw-Hill Book Co., New York, 3rd ed., 1950, page 370.
8. J. W. Buddenberg and C. R. Wilke, Ind. Eng. Chem. 41, 1345 (1949).
9. C. R. Wilke and C. V. Lee, Ind. Eng. Chem. 47, 1253 (1955).
10. J. O. Hirschfelder, R. B. Bird, and E. L. Spotz, Trans. Am. Soc. Mech. Engrs. 71, 921 (1949).
11. C. R. Wilke, Chem. Eng. Progr. 46, 95 (1950).
12. C. E. Lapple, "Fluid and Particle Mechanics," University of Delaware, Newark, Del., 1951.

APPENDIX "A"

COMPUTER PROGRAM

This appendix contains a listing of the main computer program SPRAY and its subroutines DSUBV and VSUBT. The calculations being carried out are described under "Computer Program" in the body of the report.

05-15-67

```
PROGRAM SPRAY
TYPE REAL MOLWT
TYPE REAL KSUBG
TYPE REAL NUM
DIMENSION KSUBG(20,20), VSUBG(20,20),AOFL(20,20)
DIMENSION TEMPCE(20),FAIR(20),FSTEAM(20),VSUBTE(20,20),DIMIXT(20)
DIMENSION XFRC(20,20),DPAR(20),PTOTL(20),REYNUM(20,20)
DIMENSION SMITNU(20)
DIMENSION ETAIR(20),ETASTM(20),ETAMXT(20),DIA(20),DIS(20)
COMMON TEMPC, TEMPK, FRAIR,FRSTEAM,VTER ,DIMIX,ETAMIX,RHOAIR
COMMON RHOLIQ,RHOSTM,RHOATM,PTOTAL,DSUBP
COMMON REYNO, DIAIR,DIWTR
TEMPC = 20    $ GSUBL = 0.1
DO 1 I = 1,14
TEMPK = TEMPC + 273.16
X= 647.27 - TEMPK
NUM = (3.2437814 + (5.86826E-3)*X + (1.1702379E-8)*(X**3))
DENOM = 1 +(2.1878462E-3)*X
PHI1X = NUM/DENOM
PHI2X = (2.302585   *X*PHI1X) / TEMPK
PHIP = EXPF (PHI2X)
P = 218.167/ PHIP
VLIQ = 1.0018 + .0002615*(TEMPC-20.) +(3.219E-6)*((TEMPC-20.)**2)
RHOLIQ = 1/VLIQ
RHOAIR = 0.001185
TAU=1.0/TEMPK
TAUSQ  = TAU **2
G1TAU = 82.546*TAU -(1.6246E5)*TAUSQ
G2TAU = 0.21828 -(1.2697E5)*TAUSQ
G3TAU = 3.635E-4  - (6.768E64)*(TAU**24)
BZERO = 1.89 - 2641.6*TAU*(10**(80870*TAUSQ))
B = BZERO + (BZERO**2)*(G1TAU)*(TAU)*P + (BZERO**4)*G2TAU*((TAU*P)
**3) +(BZERO**13)*G3TAU*((TAU*P)**12)
V = (4.55504*TEMPK)/P + B
RHOSTM = 1/V
RHOATM = 0.001185 + RHOSTM
DENOM = 1 + 680.1*TAU
NUM = (1.851E-5)*(TEMPK**0.5)
ETA0  = NUM/DENOM
F1OFP = (P*(1.0E-4))*(0.03103-P*(3.65E-5))
ETA   = ETA0 + F1OFP
PAIR = 1.0* TEMPK/298.0
PTOTAL = P + PAIR
FRSTEAM = P/PTOTAL
FRAIR   = PAIR/PTOTAL
ETAAIR  =(1.709E-4)*((TEMPK/273.1)**0.768)
NUM=(1.+((ETAAIR/ETA)**0.5)*((18.0/29.0)**0.25))**2
DENOM =(4/SQRTF(2.0))* ((1.0 + (29.0/18.0))**0.5)
PHI12 = NUM/DENOM
NUM = (1.0 + ((ETA/ETAAIR)**0.5)*((29.0/18.0)**0.25))**2
DENOM = (4/SQRTF(2.0))* (( 1.0 + (18.0/29.0))**0.5)
PHI21 = NUM/DENOM
DENOM = 1.0 -(FRSTEAM/FRAIR)*PHI12
TERM1 = ETAAIR/DENOM
DENOM = 1.0 + (FRAIR/FRSTEAM)*PHI21
TERM2 = ETA/DENOM
```

```
      ETAMIX = TERM1 + TERM 2
      ETAIR(I)=ETAAIR $ ETASTM(I) =ETA $ ETAMXT(I) = ETAMIX
      WRITE (51,100) TEMPC, P, G1TAU,G2TAU,G3TAU,BZERO,B,V
      WRITE(51,101) RHOATM
      MOLWT = 29.0*FRAIR  + 18.0*FRSTEAM
      TEMPCE(I)  =TEMPC  $ PTOTL(I)= PTOTAL
      FAIR(I)    = FRAIR
      FSTEAM (I) = FRSTEAM
      DSUBP = .01
      CALL DSUBV
      DIMIXT(I)  = DIMIX
      DIA(I) = DIAIR  $ DIS(I) = DIWTR
      SMITNO = ETAMIX/(RHOATM*DIMIX)
      SMITNU(I) = SMITNO
      DO 2 J = 1,11
      CALL VSUBT
      DPAR(J)    = DSUBP
      REYNUM(I,J) = REYNO
      VSUBTE(I,J)= VTER
      KSUBG(I,J)=((2+0.6*(REYNO**0.5)*(SMITNO**0.33))*DIMIX*RHOATM)/
     1(DSUBP*PTOTAL*MOLWT)
      VSUBG(I,J) = KSUBG(I,J)*82.06*TEMPK
      AOFL(I,J) = 6.0/(DSUBP*VTER*RHOLIQ)
    2 DSUBP = DSUBP + 0.01
    1 TEMPC = TEMPC + 10.0
      DO 3 I =1,14,3
      WRITE(51,107)
      WRITE (51,4)  TEMPCE(I),FAIR(I),FSTEAM(I),PTOTL(I)
      WRITE (51,102) ETAIR(I  ), ETASTM(I  ), ETAMXT(I)
      WRITE(51,106) DIA(I), DIS(I), DIMIXT(I)
      WRITE (51,8) SMITNU(I)
      WRITE (51,5) (DPAR(J),J=1,11)
      WRITE(51,9)(REYNUM(I,J),J=1,11)
      WRITE (51,6) (VSUBTE(I,J),J=1,11)
      WRITE(51,103) (KSUBG(I,J),J=1,11)
      WRITE(51,104)(VSUBG(I,J),J=1,11)
      WRITE(51,105) (AOFL(I,J),J=1,11)
      WRITE(51,4)  TEMPCE(I+1), FAIR(I+1),FSTEAM(I+1),PTOTL(I+1)
      WRITE (51,102) ETAIR(I+1), ETASTM(I+1), ETAMXT(I+1)
      WRITE (51,106) DIA(I+1), DIS(I+1),DIMIXT(I+1)
      WRITE(51,8)  SMITNU(I+1)
      WRITE (51,5)(DPAR (J),J=1,11)
      WRITE (51,9)(REYNUM (I+1,J), J=1,11)
      WRITE (51,6)(VSUBTE(I+1,J),J=1,11)
      WRITE (51,103)(KSUBG(I+1,J),J=1,11)
      WRITE (51,104) (VSUBG(I+1,J),J=1,11)
      WRITE (51,105) (AOFL(I+1,J),J=1,11)
      WRITE(51,4)  TEMPCE(I+2), FAIR(I+2),FSTEAM(I+2),PTOTL(I+2)
      WRITE (51,102) ETAIR(I+2), ETASTM(I+2), ETAMXT(I+2)
      WRITE (51,106) DIA(I+2), DIS(I+2),DIMIXT(I+2)
      WRITE(51,8)  SMITNU(I+2)
      WRITE (51,5)(DPAR (J),J=1,11)
      WRITE (51,9)(REYNUM (I+2,J), J=1,11)
      WRITE (51,6)(VSUBTE(I+2,J),J=1,11)
      WRITE (51,103)(KSUBG(I+2,J),J=1,11)
      WRITE (51,104) (VSUBG(I+2,J),J=1,11)
```

05-15-67

```
      WRITE (51,105) (AOFL(I+2,J),J=1,11)
    3 CONTINUE
    4 FORMAT( , TEMPERATURE,DEGREES C ,  F6.2,/
     1          , MOL FRACTION AIR      ,  F7.3,/
     2          , MOL FRACTION STEAM    ,  F7.3,/
     3          , TOTAL PRESSURE,ATM    ,  F7.3 )
    8 FORMAT ( , SCHMIDT NUMBER                    ,  E10.3   )
    9 FORMAT ( , REYNOLDS NO OF DROPS,      11E9.2 )
    5 FORMAT ( , PARTICLE DIA., CM    ,     11E9.2 )
    6 FORMAT ( , TERMINAL VEL. CM/SEC,      11E9.2 )
  100 FORMAT(1H1 , CALCULATION OF STEAM PROPERTIES NEEDED FOR SPRAY PERF
     1ORMANCE CALCULATIONS , /
     2, TEMPERATURE, DEG C          ,    E10.2,/
     3, PRESSURE, ATM               ,    E10.2,/
     4, G1TAU                       ,    E10.2,/
     5, G2TAU                       ,    E10.2,/
     6, G3TAU                       ,    E10.2,/
     7, BZERO                       ,    E10.2,/
     8, B                           ,    E10.2,/
     9, SPECIFIC VOLUME, CC/GRAM ,       E10.2)
  101 FORMAT( , DENSITY OF MIXTURE, F10.2)
  102 FORMAT ( , AIR VISCOSITY, POISES      ,  E10.2/
     1         , STEAM VISCOSITY, POISES    , E 10.2/
     2         , MIXTURE VISCOSITY, POISES, E 10.2)
  103 FORMAT( , KSUBG                    , 11E9.2)
  104 FORMAT ( , DEPOSITION VELOCITY, 11 E9.2      )
  105 FORMAT (, AREA PER UNIT FLOW , 11E9.2/)
  106 FORMAT( , DIFFUSIVITY OF IODINE IN AIR, SQ CM/SEC              ,E10
     1.2,/    , DIFFUSIVITY OF IODINE IN STEAM, SQ CM/SEC            ,E10
     2.2,/    , DIFFUSIVITY OF IODINE IN AIR-STEAM MIXTURE,SQ CM/SEC,E10
     3.2,)
  107 FORMAT(1H1,24X,,CALCULATION OF SPRAY PERFORMANCE FOR IODINE REMOVA
     1L, //)
      END
```

05-15-67

```
      SUBROUTINE DSUBV
      TYPE REAL NUM
      COMMON TEMPC, TEMPK, FRAIR,FRSTEAM,VTER ,DIMIX,ETAMIX,RHOAIR
      COMMON RHOLIQ,RHOSTM,RHOATM,PTOTAL,DSUBP
      COMMON REYNO, DIAIR,DIWTR
C THIS SUBROUTINE CALCULATES THE DIFFUSION COEFFICIENT IN AN AIR-WATER MIXTURE
C   OF A CONSTITUENT OF INTEREST.  THE MOL FRACTION OF THE DIFFUSING CONSTITUENT
C   IS ASSUMED TO BE EFFECTIVELY 0.
C CALCULATION OF DIFFUSION COEFFICIENT OF IODINE IN AIR SUBSCRIPT 2 FOR AIR
      EPS1K = 550.$ EPS2K = 97.0 $ EPS3K = 363.0
      EPS12K = SQRTF(EPS1K*EPS2K) $ EPS13K = SQRTF(EPS1K*EPS3K)
      COLINT = 0.3674 + 0.3478*(EPS12K/TEMPK )
      RAIR = 3.617 $ RI = 4.982 $ RIAIR =  0.5*(RAIR  + RI )
      FOFM = SQRTF((1.0/254.0) +(1.0/29.0))
      B = (10.7 - 2.46*FOFM)*1.0E-4
      PFUNT = TEMPK**1.5
      NUM = B*PFUNT*FOFM
      DENOM =PTOTAL*(RIAIR**2)*COLINT
      DIAIR = NUM/DENOM
      WRITE(51,2) EPS12K,COLINT,RIAIR,FOFM,B,PFUNT,NUM,DENOM,DIAIR
C CALCULATION OF DIFFUSION COEFF. OF IODINE IN STEAM  SUBSCRIPT 3 FOR STEAM
      COLINT = 0.3674 + 0.3478*(EPS13K/TEMPK)
      RW = 2.655 $ RIW = 0.5*(RW + RI)
      FOFM = SQRTF ((1.0/254.0) + (1.0/18.0))
      B = (10.7 - 2.46*FOFM)*1.0E-4
      NUM = B*PFUNT*FOFM
      DENOM = PTOTAL*(RIW**2)*COLINT
      DIWTR = NUM/ DENOM
      DIMIX = 1/((FRAIR/DIAIR) + (FRSTEAM/DIWTR))
      WRITE (51,1) TEMPC,DIAIR, DIWTR,DIMIX
    1 FORMAT (1H1,= DIFFUSION COEFFICIENTS=,/
     1= TEMPERATURE, DEGREES CENTIGRADE                       = F6.1  ,/
     2= DIFFUSION COEFFICIENT, IODINE-AIR AT TEMPERATURE      =  E10.2,/
     3= DIFFUSION COEFFICIENT, IODINE-STEAM AT TEMPERATURE=   E10.2,/
     4= DIFFUSION COEFFICIENT  IODINE-AIR-STEAM               =  E10.2 )
    2 FORMAT(1H1,9E10.2)
      RETURN
      END
```

05-15-67

```
      SUBROUTINE VSUBT
      TYPE REAL NUM
      COMMON TEMPC, TEMPK, FRAIR,FRSTEAM,VTER ,DIMIX,ETAMIX,RHOAIR
      COMMON RHOLIQ,RHOSTM,RHOATM,PTOTAL,DSUBP
      COMMON REYNO, DIAIR,DIWTR
      GSUBC = 980
      XPGC = GSUBC**0.714
      XPDP = DSUBP**1.142
      DELRHO = RHOLIQ - RHOATM
      XPRHOA = RHOATM**0.286
      XPDRHO = DELRHO**0.714
      XPETA  =  ETAMIX**0.428
      VTER  = 0.153*XPGC*XPDP*XPDRHO/(XPRHOA*XPETA)
      REYNO =(DSUBP*VTER*RHOATM)/ETAMIX
      IF (REYNO.GT.1000)102,103
  102 VTER = 1.74*(SQRTF((GSUBC*DSUBP*DELRHO)/RHOATM))
      REYNO = (DSUBP*VTER*RHOATM)/ETAMIX
  103 WRITE (51,101) ETAMIX,VTER
      WRITE (51,104) DSUBP
      RETURN
  101 FORMAT( 1H0
     1= VISCOSITY, POISES         =    E8.2,/
     2= TERMINAL VELOCITY,CM/SEC  =    E8.2 )
  104 FORMAT(27H DROP DIAMETER, CENTIMETERS    E8.2)
      END
```

APPENDIX "B"

RESULTS OF CALCULATIONS

This section contains the output of the machine calculations. All but the last three items should be obvious. These are:

"KSUBG = k_G in g mols/sec (cm^2)(atm)

"Deposition velocity" in cm/sec

"Area per unit flow" is a factor which can be multiplied by the liquid mass flow in g/(cm^2)(sec) to give the available contact area in cm^2/cm^3. It takes into account the effect of drop diameter and terminal velocity on the contact area.

CALCULATION OF SPRAY PERFORMANCE FOR IODINE REMOVAL

TEMPERATURE, DEGREES C	20.00
MOL FRACTION AIR	.977
MOL FRACTION STEAM	.023
TOTAL PRESSURE, ATM	1.007
AIR VISCOSITY, POISES	1.80E-04
STEAM VISCOSITY, POISES	9.55E-05
MIXTURE VISCOSITY, POISES	1.78E-04
DIFFUSIVITY OF IODINE IN AIR, SQ CM/SEC	8.42E-02
DIFFUSIVITY OF IODINE IN STEAM, SQ CM/SEC	9.38E-02
DIFFUSIVITY OF IODINE IN AIR-STEAM MIXTURE, SQ CM/SEC	8.44E-02
SCHMIDT NUMBER	1.758E+00

PARTICLE DIA., CM	1.00E-02	2.00E-02	3.00E-02	4.00E-02	5.00E-02	6.00E-02	7.00E-02	8.00E-02	9.00E-02	1.00E-01	1.10E-01
REYNOLDS NO OF DROPS	2.01E+00	8.88E+00	2.12E+01	3.92E+01	6.32E+01	9.34E+01	1.30E+02	1.73E+02	2.23E+02	2.79E+02	3.42E+02
TERMINAL VEL, CM/SEC	2.99E+01	6.59E+01	1.05E+02	1.45E+02	1.88E+02	2.31E+02	2.76E+02	3.21E+02	3.67E+02	4.14E+02	4.62E+02
KSUBG	1.06E-03	7.28E-04	6.22E-04	5.72E-04	5.43E-04	5.25E-04	5.13E-04	5.04E-04	4.98E-04	4.93E-04	4.90E-04
DEPOSITION VELOCITY	2.55E+01	1.75E+01	1.50E+01	1.38E+01	1.31E+01	1.26E+01	1.23E+0	1.21E+01	1.20E+01	1.19E+01	1.18E+01
AREA PER UNIT FLOW	2.01E+01	4.56E+00	1.91E+00	1.03E+00	6.41E-01	4.34E-01	3.12E-01	2.34E-01	1.82E-01	1.45E-01	1.18E-01

TEMPERATURE, DEGREES C	30.00
MOL FRACTION AIR	.960
MOL FRACTION STEAM	.040
TOTAL PRESSURE, ATM	1.059
AIR VISCOSITY, POISES	1.85E-04
STEAM VISCOSITY, POISES	9.95E-05
MIXTURE VISCOSITY, POISES	1.82E-04
DIFFUSIVITY OF IODINE IN AIR, SQ CM/SEC	8.54E-02
DIFFUSIVITY OF IODINE IN STEAM, SQ CM/SEC	9.57E-02
DIFFUSIVITY OF IODINE IN AIR-STEAM MIXTURE, SQ CM/SEC	8.57E-02
SCHMIDT NUMBER	1.743E+00

PARTICLE DIA., CM	1.00E-02	2.00E-02	3.00E-02	4.00E-02	5.00E-02	6.00E-02	7.00E-02	8.00E-02	9.00E-02	1.00E-01	1.10E-01
REYNOLDS NO OF DROPS	1.97E+00	8.71E+00	2.08E+01	3.84E+01	6.20E+01	9.16E+01	1.27E+02	1.70E+02	2.18E+02	2.74E+02	3.36E+02
TERMINAL VEL, CM/SEC	2.95E+01	6.50E+01	1.03E+02	1.44E+02	1.85E+02	2.28E+02	2.72E+02	3.17E+02	3.62E+02	4.09E+02	4.56E+02
KSUBG	1.04E-03	7.11E-04	6.07E-04	5.57E-04	5.29E-04	5.11E-04	4.99E-04	4.90E-04	4.84E-04	4.79E-04	4.76E-04
DEPOSITION VELOCITY	2.58E+01	1.77E+01	1.51E+01	1.39E+01	1.32E+01	1.27E+01	1.24E+01	1.22E+01	1.20E+01	1.19E+01	1.18E+01
AREA PER UNIT FLOW	2.05E+01	4.63E+00	1.94E+00	1.05E+00	6.51E-01	4.41E-01	3.17E-01	2.38E-01	1.85E-01	1.47E-01	1.20E-01

TEMPERATURE, DEGREES C	40.00
MOL FRACTION AIR	.935
MOL FRACTION STEAM	.065
TOTAL PRESSURE, ATM	1.124
AIR VISCOSITY, POISES	1.90E-04
STEAM VISCOSITY, POISES	1.04E-04
MIXTURE VISCOSITY, POISES	1.84E-04
DIFFUSIVITY OF IODINE IN AIR, SQ CM/SEC	8.56E-02
DIFFUSIVITY OF IODINE IN STEAM, SQ CM/SEC	9.65E-02
DIFFUSIVITY OF IODINE IN AIR-STEAM MIXTURE, SQ CM/SEC	8.63E-02
SCHMIDT NUMBER	1.725E+00

PARTICLE DIA., CM	1.00E-02	2.00E-02	3.00E-02	4.00E-02	5.00E-02	6.00E-02	7.00E-02	8.00E-02	9.00E-02	1.00E-01	1.10E-01
REYNOLDS NO OF DROPS	1.95E+00	8.63E+00	2.06E+01	3.81E+01	6.14E+01	9.07E+01	1.26E+02	1.68E+02	2.16E+02	2.71E+02	3.32E+02
TERMINAL VEL, CM/SEC	2.91E+01	6.42E+01	1.02E+02	1.42E+02	1.83E+02	2.25E+02	2.68E+02	3.13E+02	3.58E+02	4.03E+02	4.50E+02
KSUBG	1.01E-03	6.89E-04	5.88E-04	5.40E-04	5.12E-04	4.94E-04	4.83E-04	4.74E-04	4.68E-04	4.64E-04	4.60E-04
DEPOSITION VELOCITY	2.59E+01	1.77E+01	1.51E+01	1.39E+01	1.32E+01	1.27E+01	1.24E+01	1.22E+01	1.20E+01	1.19E+01	1.18E+01
AREA PER UNIT FLOW	2.08E+01	4.71E+00	1.98E+00	1.07E+00	6.62E-01	4.48E-01	3.22E-01	2.42E-01	1.88E-01	1.50E-01	1.22E-01

TEMPERATURE,DEGREES C 50.00
MOL FRACTION AIR .899
MOL FRACTION STEAM .101
TOTAL PRESSURE,ATM 1.206
AIR VISCOSITY, POISES 1.94*-04
STEAM VISCOSITY, POISES 1.08*-04
MIXTURE VISCOSITY, POISES 1.85*-04
DIFFUSIVITY OF IODINE IN AIR, SQ CM/SEC 8.47*-02
DIFFUSIVITY OF IODINE IN STEAM, SQ CM/SEC 9.59*-02
DIFFUSIVITY OF IODINE IN AIR-STEAM MIXTURE,SQ CM/SEC 8.57*-02
SCHMIDT NUMBER 1.706*+00

PARTICLE DIA., CM	1.00*-02	2.00*-02	3.00*-02	4.00*-02	5.00*-02	6.00*-02	7.00*-02	8.00*-02	9.00*-02	1.00*-01	1.10*-01
REYNOLDS NO OF DROPS	1.96*+00	8.66*+00	2.06*+01	3.82*+01	6.17*+01	9.11*+01	1.27*+02	1.69*+02	2.17*+02	2.72*+02	3.34*+02
TERMINAL VEL, CM/SEC	2.87*+01	6.33*+01	1.01*+02	1.40*+02	1.80*+02	2.22*+02	2.65*+02	3.08*+02	3.53*+02	3.98*+02	4.44*+02
KSUBG	9.70*-04	6.63*-04	5.66*-04	5.19*-04	4.92*-04	4.76*-04	4.64*-04	4.56*-04	4.50*-04	4.46*-04	4.43*-04
DEPOSITION VELOCITY	2.57*+01	1.76*+01	1.50*+01	1.38*+01	1.31*+01	1.26*+01	1.23*+01	1.21*+01	1.19*+01	1.18*+01	1.17*+01
AREA PER UNIT FLOW	2.12*+01	4.80*+00	2.01*+00	1.09*+00	6.74*-01	4.56*-01	3.28*-01	2.46*-01	1.91*-01	1.53*-01	1.24*-01

TEMPERATURE,DEGREES C 60.00
MOL FRACTION AIR .850
MOL FRACTION STEAM .150
TOTAL PRESSURE,ATM 1.315
AIR VISCOSITY, POISES 1.99*-04
STEAM VISCOSITY, POISES 1.12*-04
MIXTURE VISCOSITY, POISES 1.86*-04
DIFFUSIVITY OF IODINE IN AIR, SQ CM/SEC 8.24*-02
DIFFUSIVITY OF IODINE IN STEAM, SQ CM/SEC 9.37*-02
DIFFUSIVITY OF IODINE IN AIR-STEAM MIXTURE,SQ CM/SEC 8.39*-02
SCHMIDT NUMBER 1.683*+00

PARTICLE DIA., CM	1.00*-02	2.00*-02	3.00*-02	4.00*-02	5.00*-02	6.00*-02	7.00*-02	8.00*-02	9.00*-02	1.00*-01	1.10*-01
REYNOLDS NO OF DROPS	2.00*+00	8.84*+00	2.11*+01	3.90*+01	6.29*+01	9.30*+01	1.29*+02	1.72*+02	2.22*+02	2.78*+02	3.41*+02
TERMINAL VEL, CM/SEC	2.83*+01	6.24*+01	9.92*+01	1.38*+02	1.78*+02	2.19*+02	2.61*+02	3.04*+02	3.48*+02	3.92*+02	4.37*+02
KSUBG	9.23*-04	6.32*-04	5.39*-04	4.95*-04	4.70*-04	4.54*-04	4.43*-04	4.35*-04	4.30*-04	4.26*-04	4.23*-04
DEPOSITION VELOCITY	2.52*+01	1.73*+01	1.47*+01	1.35*+01	1.28*+01	1.24*+01	1.21*+01	1.19*+01	1.18*+01	1.16*+01	1.16*+01
AREA PER UNIT FLOW	2.16*+01	4.89*+00	2.05*+00	1.11*+00	6.87*-01	4.65*-01	3.34*-01	2.51*-01	1.95*-01	1.56*-01	1.27*-01

TEMPERATURE,DEGREES C 70.00
MOL FRACTION AIR .789
MOL FRACTION STEAM .211
TOTAL PRESSURE,ATM 1.459
AIR VISCOSITY, POISES 2.04*-04
STEAM VISCOSITY, POISES 1.16*-04
MIXTURE VISCOSITY, POISES 1.85*-04
DIFFUSIVITY OF IODINE IN AIR, SQ CM/SEC 7.85*-02
DIFFUSIVITY OF IODINE IN STEAM, SQ CM/SEC 8.97*-02
DIFFUSIVITY OF IODINE IN AIR-STEAM MIXTURE,SQ CM/SEC 8.06*-02
SCHMIDT NUMBER 1.659*+00

PARTICLE DIA., CM	1.00*-02	2.00*-02	3.00*-02	4.00*-02	5.00*-02	6.00*-02	7.00*-02	8.00*-02	9.00*-02	1.00*-01	1.10*-01
REYNOLDS NO OF DROPS	2.08*+00	9.18*+00	2.19*+01	4.05*+01	6.54*+01	9.66*+01	1.34*+02	1.79*+02	2.30*+02	2.89*+02	3.54*+02
TERMINAL VEL, CM/SEC	2.78*+01	6.14*+01	9.76*+01	1.35*+02	1.75*+02	2.15*+02	2.57*+02	2.99*+02	3.42*+02	3.86*+02	4.30*+02
KSUBG	8.66*-04	5.94*-04	5.08*-04	4.66*-04	4.43*-04	4.28*-04	4.18*-04	4.11*-04	4.06*-04	4.02*-04	3.99*-04
DEPOSITION VELOCITY	2.44*+01	1.67*+01	1.43*+01	1.31*+01	1.25*+01	1.21*+01	1.18*+01	1.16*+01	1.14*+01	1.13*+01	1.12*+01
AREA PER UNIT FLOW	2.21*+01	5.00*+00	2.10*+00	1.13*+00	7.02*-01	4.75*-01	3.42*-01	2.57*-01	1.99*-01	1.59*-01	1.30*-01

TEMPERATURE,DEGREES C 80.00
MOL FRACTION AIR .717
MOL FRACTION STEAM .283
TOTAL PRESSURE,ATM 1.652
AIR VISCOSITY, POISES 2.08*-04
STEAM VISCOSITY, POISES 1.20*-04
MIXTURE VISCOSITY, POISES 1.83*-04
DIFFUSIVITY OF IODINE IN AIR, SQ CM/SEC 7.31*-02
DIFFUSIVITY OF IODINE IN STEAM, SQ CM/SEC 8.40*-02
DIFFUSIVITY OF IODINE IN AIR-STEAM MIXTURE,SQ CM/SEC 7.59*-02
SCHMIDT NUMBER 1.633*+00

PARTICLE DIA., CM	1.00*-02	2.00*-02	3.00*-02	4.00*-02	5.00*-02	6.00*-02	7.00*-02	8.00*-02	9.00*-02	1.00*-01	1.10*-01
REYNOLDS NO OF DROPS	2.20*+00	9.71*+00	2.32*+01	4.29*+01	6.92*+01	1.02*+02	1.42*+02	1.89*+02	2.44*+02	3.05*+02	3.74*+02
TERMINAL VEL, CM/SEC	2.73*+01	6.02*+01	9.57*+01	1.33*+02	1.71*+02	2.11*+02	2.52*+02	2.93*+02	3.35*+02	3.78*+02	4.22*+02
KSUBG	7.99*-04	5.51*-04	4.72*-04	4.34*-04	4.13*-04	3.99*-04	3.90*-04	3.84*-04	3.79*-04	3.76*-04	3.73*-04
DEPOSITION VELOCITY	2.32*+01	1.60*+01	1.37*+01	1.26*+01	1.20*+01	1.16*+01	1.13*+01	1.11*+01	1.10*+01	1.09*+01	1.08*+01
AREA PER UNIT FLOW	2.26*+01	5.13*+00	2.15*+00	1.16*+00	7.20*-01	4.87*-01	3.50*-01	2.63*-01	2.05*-01	1.63*-01	1.33*-01

TEMPERATURE,DEGREES C 90.00
MOL FRACTION AIR .638
MOL FRACTION STEAM .362
TOTAL PRESSURE,ATM 1.911
AIR VISCOSITY, POISES 2.13*-04
STEAM VISCOSITY, POISES 1.25*-04
MIXTURE VISCOSITY, POISES 1.81*-04
DIFFUSIVITY OF IODINE IN AIR, SQ CM/SEC 6.67*-02
DIFFUSIVITY OF IODINE IN STEAM, SQ CM/SEC 7.70*-02
DIFFUSIVITY OF IODINE IN AIR-STEAM MIXTURE,SQ CM/SEC 7.01*-02
SCHMIDT NUMBER 1.607*+00

PARTICLE DIA., CM	1.00*-02	2.00*-02	3.00*-02	4.00*-02	5.00*-02	6.00*-02	7.00*-02	8.00*-02	9.00*-02	1.00*-01	1.10*-01
REYNOLDS NO OF DROPS	2.37*+00	1.04*+01	2.49*+01	4.61*+01	7.44*+01	1.10*+02	1.53*+02	2.04*+02	2.62*+02	3.28*+02	4.03*+02
TERMINAL VEL, CM/SEC	2.66*+01	5.88*+01	9.34*+01	1.30*+02	1.67*+02	2.06*+02	2.46*+02	2.86*+02	3.28*+02	3.69*+02	4.12*+02
KSUBG	7.26*-04	5.03*-04	4.32*-04	3.99*-04	3.80*-04	3.68*-04	3.60*-04	3.54*-04	3.50*-04	3.47*-04	3.45*-04
DEPOSITION VELOCITY	2.16*+01	1.50*+01	1.29*+01	1.19*+01	1.13*+01	1.10*+01	1.07*+01	1.05*+01	1.04*+01	1.03*+01	1.03*+01
AREA PER UNIT FLOW	2.33*+01	5.28*+00	2.22*+00	1.20*+00	7.42*-01	5.02*-01	3.61*-01	2.71*-01	2.11*-01	1.68*-01	1.37*-01

TEMPERATURE,DEGREES C 100.00
MOL FRACTION AIR .556
MOL FRACTION STEAM .444
TOTAL PRESSURE,ATM 2.252
AIR VISCOSITY, POISES 2.17*-04
STEAM VISCOSITY, POISES 1.30*-04
MIXTURE VISCOSITY, POISES 1.79*-04
DIFFUSIVITY OF IODINE IN AIR, SQ CM/SEC 5.95*-02
DIFFUSIVITY OF IODINE IN STEAM, SQ CM/SEC 6.90*-02
DIFFUSIVITY OF IODINE IN AIR-STEAM MIXTURE,SQ CM/SEC 6.34*-02
SCHMIDT NUMBER 1.582*+00

PARTICLE DIA., CM	1.00*-02	2.00*-02	3.00*-02	4.00*-02	5.00*-02	6.00*-02	7.00*-02	8.00*-02	9.00*-02	1.00*-01	1.10*-01
REYNOLDS NO OF DROPS	2.58*+00	1.14*+01	2.71*+01	5.03*+01	8.11*+01	1.20*+02	1.67*+02	2.22*+02	2.86*+02	3.58*+02	4.39*+02
TERMINAL VEL, CM/SEC	2.59*+01	5.71*+01	9.07*+01	1.26*+02	1.63*+02	2.00*+02	2.39*+02	2.78*+02	3.18*+02	3.59*+02	4.00*+02
KSUBG	6.49*-04	4.53*-04	3.91*-04	3.61*-04	3.45*-04	3.34*-04	3.27*-04	3.22*-04	3.19*-04	3.16*-04	3.14*-04
DEPOSITION VELOCITY	1.99*+01	1.39*+01	1.20*+01	1.11*+01	1.06*+01	1.02*+01	1.00*+01	9.87*+00	9.76*+00	9.69*+00	9.63*+00
AREA PER UNIT FLOW	2.42*+01	5.48*+00	2.30*+00	1.24*+00	7.70*-01	5.21*-01	3.75*-01	2.81*-01	2.19*-01	1.74*-01	1.42*-01

TEMPERATURE,DEGREES C 110.00
MOL FRACTION AIR .476
MOL FRACTION STEAM .524
TOTAL PRESSURE,ATM 2.700
AIR VISCOSITY, POISES 2.22E-04
STEAM VISCOSITY, POISES 1.35E-04
MIXTURE VISCOSITY, POISES 1.77E-04
DIFFUSIVITY OF IODINE IN AIR, SQ CM/SEC 5.22E-02
DIFFUSIVITY OF IODINE IN STEAM, SQ CM/SEC 6.07E-02
DIFFUSIVITY OF IODINE IN AIR-STEAM MIXTURE,SQ CM/SEC 5.63E-02
SCHMIDT NUMBER 1.562E+00

PARTICLE DIA., CM	1.00E-02	2.00E-02	3.00E-02	4.00E-02	5.00E-02	6.00E-02	7.00E-02	8.00E-02	9.00E-02	1.00E-01	1.10E-01
REYNOLDS NO OF DROPS	2.84E+00	1.25E+01	2.99E+01	5.53E+01	8.92E+01	1.32E+02	1.83E+02	2.44E+02	3.14E+02	3.94E+02	4.83E+02
TERMINAL VEL, CM/SEC	2.50E+01	5.51E+01	8.75E+01	1.22E+02	1.57E+02	1.93E+02	2.30E+02	2.68E+02	3.07E+02	3.46E+02	3.86E+02
KSUBG	5.73E-04	4.03E-04	3.49E-04	3.24E-04	3.09E-04	3.00E-04	2.94E-04	2.90E-04	2.87E-04	2.85E-04	2.84E-04
DEPOSITION VELOCITY	1.80E+01	1.27E+01	1.10E+01	1.02E+01	9.72E+00	9.44E+00	9.26E+00	9.13E+00	9.03E+00	8.96E+00	8.91E+00
AREA PER UNIT FLOW	2.53E+01	5.72E+00	2.40E+00	1.30E+00	8.04E-01	5.44E-01	3.91E-01	2.94E-01	2.28E-01	1.82E-01	1.49E-01

TEMPERATURE,DEGREES C 120.00
MOL FRACTION AIR .402
MOL FRACTION STEAM .598
TOTAL PRESSURE,ATM 3.279
AIR VISCOSITY, POISES 2.26E-04
STEAM VISCOSITY, POISES 1.41E-04
MIXTURE VISCOSITY, POISES 1.76E-04
DIFFUSIVITY OF IODINE IN AIR, SQ CM/SEC 4.51E-02
DIFFUSIVITY OF IODINE IN STEAM, SQ CM/SEC 5.27E-02
DIFFUSIVITY OF IODINE IN AIR-STEAM MIXTURE,SQ CM/SEC 4.93E-02
SCHMIDT NUMBER 1.546E+00

PARTICLE DIA., CM	1.00E-02	2.00E-02	3.00E-02	4.00E-02	5.00E-02	6.00E-02	7.00E-02	8.00E-02	9.00E-02	1.00E-01	1.10E-01
REYNOLDS NO OF DROPS	3.14E+00	1.38E+01	3.30E+01	6.11E+01	9.86E+01	1.46E+02	2.03E+02	2.70E+02	3.47E+02	4.35E+02	5.34E+02
TERMINAL VEL, CM/SEC	2.39E+01	5.28E+01	8.39E+01	1.17E+02	1.50E+02	1.85E+02	2.21E+02	2.57E+02	2.94E+02	3.32E+02	3.70E+02
KSUBG	4.99E-04	3.54E-04	3.08E-04	2.87E-04	2.75E-04	2.67E-04	2.62E-04	2.59E-04	2.56E-04	2.54E-04	2.53E-04
DEPOSITION VELOCITY	1.61E+01	1.14E+01	9.95E+00	9.25E+00	8.86E+00	8.62E+00	8.46E+00	8.35E+00	8.27E+00	8.21E+00	8.17E+00
AREA PER UNIT FLOW	2.66E+01	6.02E+00	2.53E+00	1.36E+00	8.46E-01	5.73E-01	4.12E-01	3.09E-01	2.40E-01	1.92E-01	1.56E-01

TEMPERATURE,DEGREES C 130.00
MOL FRACTION AIR .337
MOL FRACTION STEAM .663
TOTAL PRESSURE,ATM 4.019
AIR VISCOSITY, POISES 2.30E-04
STEAM VISCOSITY, POISES 1.47E-04
MIXTURE VISCOSITY, POISES 1.76E-04
DIFFUSIVITY OF IODINE IN AIR, SQ CM/SEC 3.85E-02
DIFFUSIVITY OF IODINE IN STEAM, SQ CM/SEC 4.52E-02
DIFFUSIVITY OF IODINE IN AIR-STEAM MIXTURE,SQ CM/SEC 4.27E-02
SCHMIDT NUMBER 1.537E+00

PARTICLE DIA., CM	1.00E-02	2.00E-02	3.00E-02	4.00E-02	5.00E-02	6.00E-02	7.00E-02	8.00E-02	9.00E-02	1.00E-01	1.10E-01
REYNOLDS NO OF DROPS	3.47E+00	1.53E+01	3.65E+01	6.75E+01	1.09E+02	1.61E+02	2.24E+02	2.98E+02	3.84E+02	4.81E+02	5.90E+02
TERMINAL VEL, CM/SEC	2.28E+01	5.02E+01	7.98E+01	1.11E+02	1.43E+02	1.76E+02	2.10E+02	2.45E+02	2.80E+02	3.16E+02	3.52E+02
KSUBG	4.32E-04	3.09E-04	2.70E-04	2.52E-04	2.42E-04	2.36E-04	2.32E-04	2.29E-04	2.27E-04	2.25E-04	2.24E-04
DEPOSITION VELOCITY	1.43E+01	1.02E+01	8.94E+00	8.34E+00	8.01E+00	7.80E+00	7.66E+00	7.57E+00	7.50E+00	7.45E+00	7.42E+00
AREA PER UNIT FLOW	2.82E+01	6.39E+00	2.68E+00	1.45E+00	8.98E-01	6.07E-01	4.37E-01	3.28E-01	2.55E-01	2.03E-01	1.66E-01

TEMPERATURE, DEGREES C	140.00
MOL FRACTION AIR	.280
MOL FRACTION STEAM	.720
TOTAL PRESSURE, ATM	4.953
AIR VISCOSITY, POISES	2.35=-04
STEAM VISCOSITY, POISES	1.53=-04
MIXTURE VISCOSITY, POISES	1.77=-04
DIFFUSIVITY OF IODINE IN AIR, SQ CM/SEC	3.27=-02
DIFFUSIVITY OF IODINE IN STEAM, SQ CM/SEC	3.85=-02
DIFFUSIVITY OF IODINE IN AIR-STEAM MIXTURE, SQ CM/SEC	3.67=-02
SCHMIDT NUMBER	1.534=+00

PARTICLE DIA., CM	1.00=-02	2.00=-02	3.00=-02	4.00=-02	5.00=-02	6.00=-02	7.00=-02	8.00=-02	9.00=-02	1.00=-01	1.10=-01
REYNOLDS NO OF DROPS	3.82=+00	1.69=+01	4.02=+01	7.44=+01	1.20=+02	1.77=+02	2.47=+02	3.28=+02	4.23=+02	5.30=+02	6.50=+02
TERMINAL VEL. CM/SEC	2.15=+01	4.75=+01	7.54=+01	1.05=+02	1.35=+02	1.66=+02	1.98=+02	2.31=+02	2.64=+02	2.98=+02	3.32=+02
KSUBG	3.71=-04	2.68=-04	2.36=-04	2.20=-04	2.12=-04	2.07=-04	2.03=-04	2.01=-04	1.99=-04	1.98=-04	1.97=-04
DEPOSITION VELOCITY	1.26=+01	9.08=+00	7.99=+00	7.47=+00	7.19=+00	7.01=+00	6.90=+00	6.82=+00	6.76=+00	6.72=+00	6.70=+00
AREA PER UNIT FLOW	3.01=+01	6.82=+00	2.86=+00	1.55=+00	9.59=-01	6.49=-01	4.66=-01	3.50=-01	2.72=-01	2.17=-01	1.77=-01

TEMPERATURE, DEGREES C	150.00
MOL FRACTION AIR	.232
MOL FRACTION STEAM	.768
TOTAL PRESSURE, ATM	6.118
AIR VISCOSITY, POISES	2.39=-04
STEAM VISCOSITY, POISES	1.61=-04
MIXTURE VISCOSITY, POISES	1.80=-04
DIFFUSIVITY OF IODINE IN AIR, SQ CM/SEC	2.77=-02
DIFFUSIVITY OF IODINE IN STEAM, SQ CM/SEC	3.27=-02
DIFFUSIVITY OF IODINE IN AIR-STEAM MIXTURE, SQ CM/SEC	3.14=-02
SCHMIDT NUMBER	1.539=+00

PARTICLE DIA., CM	1.00=-02	2.00=-02	3.00=-02	4.00=-02	5.00=-02	6.00=-02	7.00=-02	8.00=-02	9.00=-02	1.00=-01	1.10=-01
REYNOLDS NO OF DROPS	4.18=+00	1.85=+01	4.40=+01	8.15=+01	1.31=+02	1.94=+02	2.70=+02	3.60=+02	4.63=+02	5.80=+02	7.11=+02
TERMINAL VEL. CM/SEC	2.02=+01	4.46=+01	7.08=+01	9.84=+01	1.27=+02	1.56=+02	1.86=+02	2.17=+02	2.48=+02	2.80=+02	3.12=+02
KSUBG	3.18=-04	2.32=-04	2.05=-04	1.92=-04	1.85=-04	1.81=-04	1.78=-04	1.76=-04	1.75=-04	1.74=-04	1.73=-04
DEPOSITION VELOCITY	1.10=+01	8.04=+00	7.11=+00	6.67=+00	6.42=+00	6.28=+00	6.18=+00	6.11=+00	6.07=+00	6.04=+00	6.01=+00
AREA PER UNIT FLOW	3.24=+01	7.34=+00	3.08=+00	1.66=+00	1.03=+00	6.98=-01	5.01=-01	3.77=-01	2.93=-01	2.34=-01	1.90=-01

TEMPERATURE, DEGREES C	-0
MOL FRACTION AIR	-0
MOL FRACTION STEAM	-0
TOTAL PRESSURE, ATM	-0
AIR VISCOSITY, POISES	-6.48-261
STEAM VISCOSITY, POISES	-6.48-261
MIXTURE VISCOSITY, POISES	-6.48-261
DIFFUSIVITY OF IODINE IN AIR, SQ CM/SEC	-6.48-261
DIFFUSIVITY OF IODINE IN STEAM, SQ CM/SEC	-6.48-261
DIFFUSIVITY OF IODINE IN AIR-STEAM MIXTURE, SQ CM/SEC	-6.48-261
SCHMIDT NUMBER	-6.477-261

PARTICLE DIA., CM	1.00=-02	2.00=-02	3.00=-02	4.00=-02	5.00=-02	6.00=-02	7.00=-02	8.00=-02	9.00=-02	1.00=-01	1.10=-01
REYNOLDS NO OF DROPS	-6.48-261	-6.48-261	-6.48-261	-6.48-261	-6.48-261	-6.48-261	-6.48-261	-6.48-261	-6.48-261	-6.48-261	-6.48-261
TERMINAL VEL. CM/SEC	-6.48-261	-6.48-261	-6.48-261	-6.48-261	-6.48-261	-6.48-261	-6.48-261	-6.48-261	-6.48-261	-6.48-261	-6.48-261
KSUBG	-6.48-261	-6.48-261	-6.48-261	-6.48-261	-6.48-261	-6.48-261	-6.48-261	-6.48-261	-6.48-261	-6.48-261	-6.48-261
DEPOSITION VELOCITY	-6.48-261	-6.48-261	-6.48-261	-6.48-261	-6.48-261	-6.48-261	-6.48-261	-6.48-261	-6.48-261	-6.48-261	-6.48-261
AREA PER UNIT FLOW	-6.48-261	-6.48-261	-6.48-261	-6.48-261	-6.48-261	-6.48-261	-6.48-261	-6.48-261	-6.48-261	-6.48-261	-6.48-261

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

INTERNAL DISTRIBUTION

1. R. D. Ackley
2. R. E. Adams
3. T. D. Anderson
4. C. J. Barton
5. S. E. Beall
6. M. Bender
7. R. F. Benson
8. J. P. Blakely
9. G. E. Boyd
10. R. B. Briggs
11. W. E. Browning, Jr.
12. J. R. Buchanan
13-15. W. B. Cottrell
16. E. N. Cramer
17. G. E. Creek
18. F. L. Culler, Jr.
19. W. K. Ergen
20. D. E. Ferguson
21. M. H. Fontana
22. A. P. Fraas
23. J. K. Franzreb
24. S. H. Freid
25. J. S. Gill
26. W. R. Grimes
27. C. E. Guthrie
28. R. P. Hammond
29. P. N. Haubenreich
30. P. P. Holz
31. W. H. Jordan
32. S. I. Kaplan
33. P. R. Kasten
34. G. W. Keilholtz
35. M. J. Kelly
36. O. H. Klepper
37. J. O. Kolb
38. T. S. Kress
39. J. A. Lane
40. C. E. Larson
41. C. G. Lawson
42. T. F. Lomenick
43. R. A. Lorenz
44. M. I. Lundin
45. R. N. Lyon
46. H. G. MacPherson
47. R. E. MacPherson
48. A. P. Malinauskas
49. W. J. Martin
50. H. C. McCurdy
51. J. W. Michel
52. R. P. Milford
53. A. J. Miller
54. F. H. Neill
55. G. W. Parker
56-65. L. F. Parsly, Jr.
66. P. Patriarca
67. A. M. Perry
68. R. H. Rainey
69. B. F. Roberts
70. G. C. Robinson
71. M. W. Rosenthal
72-81. T. H. Row
82. A. W. Savolainen
83. C. L. Segaser
84. L. B. Shappert
85. L. J. Shersky
86. R. P. Shields
87. M. D. Silverman
88. O. Sisman
89. M. J. Skinner
90. C. M. Smith
91. B. A. Soldano
92. I. Spiewak
93. G. M. Tolson
94. D. B. Trauger
95. J. Truitt
96. C. S. Walker
97. J. L. Wantland
98. W. T. Ward
99. C. D. Watson
100. G. M. Watson
101. G. A. West
102. G. D. Whitman
103. F. J. Witt
104. W. D. Yuille
105. F. C. Zapp
106. Nuclear Safety Info. Center
107-108. Central Research Library
109-110. ORNL-Y-12 Technical Library Doc. Section
111-113. Laboratory Records
114. Laboratory Records, ORNL R.C.

EXTERNAL DISTRIBUTION

115-129. Division of Technical Information Extension (DTIE)
130. Research and Development Division, ORO
131-132. Reactor Division, ORO
133-372. Nuclear Safety Program